Monitoring the Indian Summer Monsoon evolution using TRMM/GPM

Amit Bhardwaj[1, 3] and Vasubandhu Misra[1, 2, 3]

[1]Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, USA

[2]Department of Earth, Ocean and Atmospheric Science, Florida State University, Tallahassee, Florida, USA

[3]Florida Climate Institute, Florida State University, Tallahassee, Florida, USA

Abstract

We make use of satellite-based rainfall products from both the Global Precipitation Measurement (GPM) Integrated Multiscale Retrievals for GPM (IMERG) and its predecessor, the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA), and daily rainfall analysis based on rain gauge measurement available from the Indian Meteorological Department (IMD) to objectively define local onset and demise at 36 Meteorological subdivisions of the Indian Summer Monsoon. This local definition is also anchored to the All India averaged Rainfall (AIR) monsoon onset and demise to avoid detection of false local onset and demise. It is also shown that the early monsoon rains over northeast India has a predictive potential for the following seasonal length of the Indian Summer Monsoon over rest of India.

Datasets and Methodology

Rain gauge observation of the IMD available for 104 years (1902-2005) (Pai et al. 2014a, b) and satellite-based TRMM (1998-2015) products are utilized to compute onset and demise at 0.25°x0.25° grid interval. Three years of GPM (2015-2017) products are then used for testing an experimental forecast outlook. The onset (demise) of AIR is defined as the first day after the minimum (maximum) in daily cumulative anomaly of AIR is reached in the year (Noska and Misra 2016). The daily cumulative anomaly $C'_m(i)$ of AIR for day i of year m is computed as:

$$C'_m(i) = \sum_{n=1}^{i}\left[A_m(n) - \bar{\bar{C}}\right] \text{ where,}$$

$$\bar{\bar{C}} = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N} A(m,n)$$

$A_m(n)$ is the daily AIR for day n of year m, and $\bar{\bar{C}}$ is the climatology of the annual mean of AIR over N (=365/366) days for M years.

To define the local onset and demise at every grid point over the domain we first compute the climatological local onset $(\overline{o(i)_x})$ and demise $(\overline{d(i)_x})$ from the daily cumulative anomaly $(cl'_x(i))$ of the daily climatology of rain at the grid point in the same way as for the AIR (but this local definition can be potentially scaled to any spatial discretization that suits user needs):

$$cl'_x(i) = \sum_{n=1}^{i}\left[\bar{r}_x(n) - \overline{\overline{c_x}}\right]$$

where, $\bar{r}_x$ is the climatological rain at grid point x for day n and $\overline{\overline{c_x}}$ is annual mean climatology of rain at grid point x:

$$\bar{\bar{c}}_x = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N} r(m,n)_x$$

Similarly, we define the climatological onset $(\overline{O(i)_x})$ and demise $(\overline{D(i)_x})$ from the daily cumulative anomaly of the daily climatological AIR. We then compute the difference (b_x) between the climatological local $(\overline{o(j)_x})$ and climatological AIR onset $(\overline{O(i)})$ as:

$$b_x = \overline{o(j)_x} - \overline{O(i)}$$

and similarly, the difference (d_x) between the climatological local $(\overline{d(j)_x})$ and AIR demise $(\overline{D(i)})$ as:

$$d_x = \overline{d(j)_x} - \overline{D(i)}$$

The climatological departures of local with AIR-based onset/demise over the 104-year period of the dataset gives a robust estimate of the phase lag (in days), with the transients being averaged out. We then define local onset $(lc_m(i)_x)$ and demise $(ld_m(i)_x)$ for a given year *m* and grid point *x* from the daily cumulative anomaly for the year *m* by finding conservatively (the nearest) minimum and maximum near the immediate vicinity of $(O_m(i) \pm kb_x)$ and $(D_m(i) \pm pd_x)$, where, $k = (1 + q\sigma_{b_x})$ and $p = (1 + r\sigma_{b_x})$. $\sigma_{b_x}, \sigma_{d_x}$, are the standard deviations of bx and dx, *q* and *r* are fractions that are incrementally increased from zero. (Misra et al 2017).

Local Onset/demise Climatology

The climatological local onset, demise, seasonal accumulation of rainfall of the ISM are shown in first column of Figs. 1a, b, c. In general, the progression of the local onset of the ISM in Fig.1a follows the typical isochrone progression of the ISM from the southwest corner across to the northwest regions of India. However, the southeastern part of India (Tamil Nadu) and over northern tip of India (northwestern part of Jammu and Kashmir) experience a very delayed onset of the ISM (Fig. 1a), as these regions climatologically receive far less summer season rainfall than other parts of the country (Fig.1c). TRMM and GPM draws similar conclusion as shown in second and third corresponding columns.

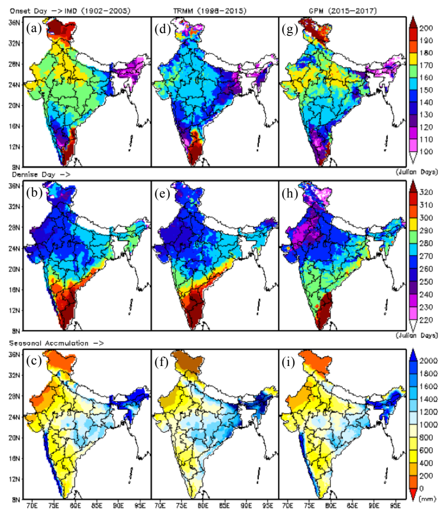
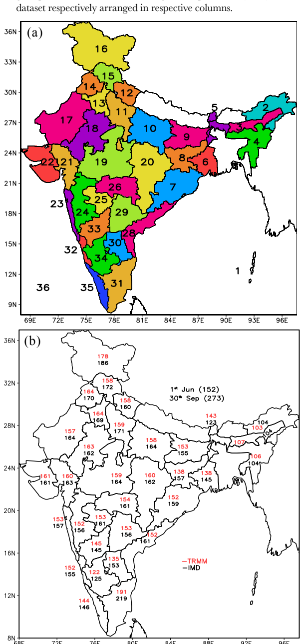


Figure 1: First, second and third rows shows the climatological onset, demise date (in Julian days), and seasonal accumulation of rainfall (mm) of the Indian Summer Monsoon (ISM) defined at every grid point for Indian Meteorological Department (IMD), TRMM and GPM gridded rainfall dataset respectively arranged in respective columns.



1. Andaman & Nicobar Islands
2. Arunachal Pradesh
3. Assam & Meghalaya
4. Naga. Manni. Mizo & Tripura
5. Sub-Him. West Bengal & Sikkim
6. Gangetic West Bengal
7. Orissa
8. Jharkhand
9. Bihar
10. East Uttar Pradesh
11. West Uttar Pradesh
12. Uttaranchal
13. Haryana, Chandigarh & Delhi
14. Punjab
15. Himachal Pradesh
16. Jammu & Kashmir
17. West Rajasthan
18. East Rajasthan
19. West Madhya Pradesh
20. East Madhya Pradesh
21. Gujarat
22. Saurashtra, Kutch & Diu
23. Konkan & Goa
24. Madhya Maharashtra
25. Marathwada
26. Vidarbha
27. Chhattisgarh
28. Coastal Andhra Pradesh
29. Telangana
30. Rayalaseema
31. Tamil Nadu & Pondicherry
32. Coastal Karnataka
33. North Interior Karnataka
34. South Interior Karnataka
35. Kerala
36. Lakshadweep

Figure 3: (a) 36 Meteorological sub-divisions of India, Name of each subdivision is given in the list (b) MSDs corresponding onset day (Julian days) from IMD (black) and TRMM (Red) are compared. (Note: subdivisions 1 and 36 are not used in analysis, also updated data for subdivision 27 (Chhattisgarh) is not available.

Results

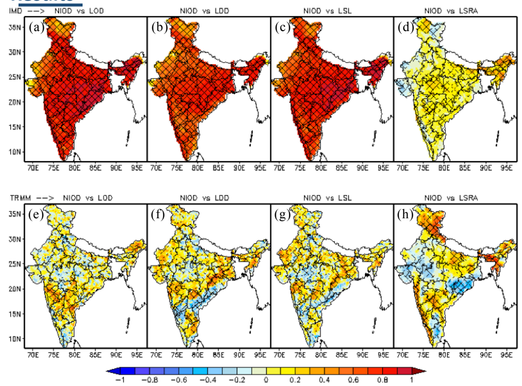


Figure 2: The correlation of the area average onset date over northeast India (NIOD) with corresponding IMD (first row) and TRMM (Second row) local onset date (LOD), demise dates (LDD), seasonal length (LSL) and seasonal rainfall anomalies (LSRA) of the Indian Summer monsoon. The hatched regions indicate passing bootstrap test at 5% significance level.

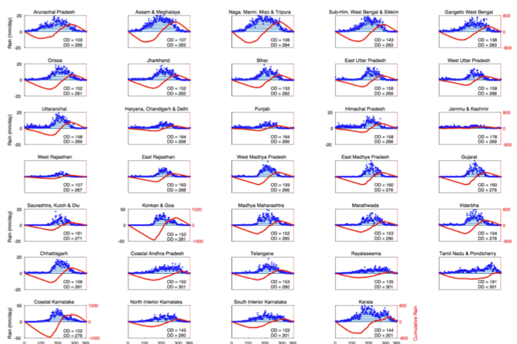


Figure 4: Time series of daily rainfall climatology (IMD) of the 33-Meteorological sub-divisions of India (MSDs; blue dots) and the corresponding cumulative daily anomaly curve (red line) with onset (OD) and Demise (DD) dates marked in Julian days.

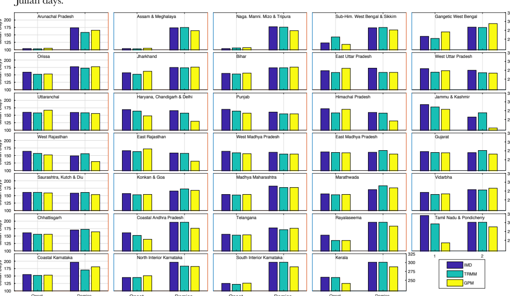


Figure 5: Comparison of IMD, TRMM and GPM onset/demise for corresponding MSDs.

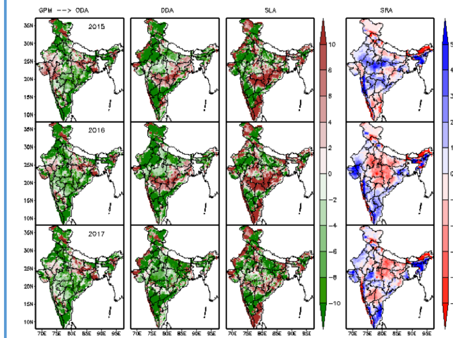


Figure 6: GPM three years (2015, 2016 & 2017) onset , demise and seasonal length anomalies. Note the striking similarity in the sign of the anomalies of the onset date anomaly (ODA), demise date anomaly (DDA) and seasonal length anomaly (SLA) over northeast India with the rest of India.

Conclusions

An objective definition of local onset and demise of the ISM is introduced, which has many attractive features:

1) The definition is scalable to any spatial resolution; therefore it can be easily adapted for any application or dataset.
2) The chance for detection of false onset and demise is minimized by anchoring to AIR seasonal cycle.
3) It is solely based on rainfall; therefore it is comparatively easy to implement as it does not require multiple sources of data.
4) It is quite apparent that early (later) onset of the ISM over Northeast India (NI) is very strongly associated with early (later) onset (Fig. 2a), early (later) demise (Fig. 2b) and longer (shorter) length (Fig. 2c) of ISM over rest of India. However, the relationship of the onset of ISM over NI with seasonal rainfall anomalies is weekly correlated over rest of India. Because onset of summer rains in NI occurs almost a month earlier than rest of India, there is a potential to tap the predictive skill of the onset of rains over NI for predicting onset, demise, and seasonal length over rest of the India.
5) We further analyzed the gridded rainfall analysis to develop regional onset, demise, seasonal length and the seasonal accumulation of rainfall over 33 meteorological subdivisions (MSDs) of India as shown in Figs. 3a. The onset and demise dates of the ISM in these 33 MSDs were found to be comparable in IMD, TRMM, and GPM datasets as shown in Fig. 5.

References

Misra, V., A. Bhardwaj, and A. Mishra, 2017: Local onset and demise of the Indian summer monsoon. Clim. Dyn. Doi:10.1007/s00382-017-3924-2.

Noska, R., and Misra, V., 2016. Characterizing the onset and demise of the Indian summer monsoon. *Geophysical Research Letters, 43(9)*, pp.4547-4554.

Pai, D. S., L. Sridhar, M. Rajeevan, O. P. Sreejith, N. S. Satbhai, and B. Mukhopadhyay, 2014a: Development of a new high spatial resolution (0.25°x0.25°) long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region, *Mausam*, **65 (1)**, 1-18.

Pai, D. S., L. Sridhar, M. R. Badwaik, and M. Rajeevan, 2014b: Analysis of the daily rainfall events over India using a new long period (1901-2010) high resolution (0.25°×0.25°) gridded rainfall data set, *Climate Dyn.*, 45(3-4), doi:10.1007/s00382-014-2307-1.

Acknowledgements

The project is support by NASA. The project is funded at FSU (lead institution, grant number NNX17AG72G S001 & NNX17AG72G S003. We also thank the Indian Meteorological Department for the availability of the daily rain analysis over India.